decrease is most marked during the warmer half-year, the season when convection is greatest. The air over the interior valleys becomes warmed under the intense insolation and expands upward, causing a slight pressure gradient which increases with elevation. The air then starts to flow down this gradient toward the ocean and the cool air over the ocean flows landward to replace the warmed air flowing off aloft (figs. 2 and 3). At night, the air over the ocean is warmer than that over the land owing to the more rapid radiation of the land surface, and the reverse action takes place, a landward breeze aloft and a seaward breeze below. This is the theory of the origin of the land and sea breeze.[1]

Mount Tamalpais probably penetrates the lower part of the transition zone between this seaward upper wind and the landward lower current. Therefore light variable winds would be expected during the time these convection-caused currents are operating.

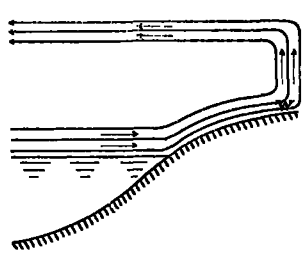

FIG. 2.—Actual circulation under seabreeze conditions (Sandström).

From observations of cloud movement, this upper seaward current is believed to blow from the northeast. Clouds are seldom recorded as moving from easterly quarters, but when they are the direction is almost always from the northeast. This freedom from clouds in this air current is probably due to adiabatic heating.

The decrease in velocity at this elevation is simultaneous with the beginning of convection in the interior valleys, i. e., about 9 a. m. It is thought, then, that the outflowing air aloft, descending as it progresss, tends to cause a change in the wind direction at this level in a clockwise direction, since during the middle of the day north and northeast winds are often recorded. This easterly wind flowing seaward at high altitudes, if it is not always strong enough to cause a change in the regular wind direction, will at least interfere and cause a decrease in velocity. In the middle of the afternoon, when convection in the interior valleys is decreasing, the wind velocity at this station begins again to increase; it reaches a maximum during the night when the air aloft is moving landward and would tend to increase velocities, and this is in exact agreement with the observed facts.

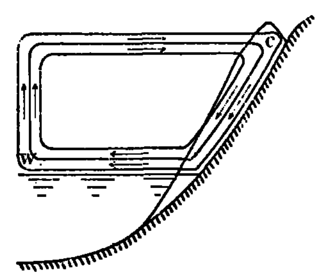

FIG. 3.—Circulation of a land-breeze (Sandström).

On rare occasions a northeast velocity of from 30 to 60 miles an hour is recorded. It is believed, however, that these high northeast winds are the result of pressure distribution rather than local convection, because they occur usually during the cooler part of the year. This belief is further strengthened by the fact that the drift of smoke over the surrounding towns and cities shows the northeast trend ofthe wind to extend down to sealevel.

Some idea of the height to which the seabreeze extends along the coast in this vicinity can be gained from observations made on Mount Tamalpais during periods when fog is prevalent over adjacent lowlands and over the ocean, a frequent condition during extended periods in summer. The estimated average height of the seabreeze in this vicinity is between 800 and 1,000 feet, assuming that it does not extend above the upper limits of the fog. This seems probable, since the main cause of fog along this coast is believed to be the mixture of air masses having different temperatures and relative humidities. There is no reason to believe that this mixture does not extend to the upper limits of the moisture-bearing wind.

Another fact that seems to strengthen the belief that the seabreeze does not extend to this level is the difference in time between the beginning of the wind at sealevel and the beginning at this elevation. In the former case the time is the middle of the forenoon, while it is retarded until the middle of the afternoon in the latter. The converse would be expected, since the surface wind encounters more friction, which would tend to retard it and cause it to lag behind the wind at somewhat higher levels.

Still another argument in favor of this hypothesis is the low relative humidity sometimes recorded at this station when the wind is northwest. For example, the case of June 13, 1916, at 5 a. m., can be cited. Fog covered the entire surrounding country below the station. The wind here was light northwest, the temperature 68.5°F., 15 to 20 degrees warmer than the air at sealevel, and the relative humidity but 5 per cent. To produce saturation, this air would have had to be cooled to 0° F. Were this wind a true seabreeze coming off the ocean, the relative humidity could not be so low, nor would the temperature be so high. It seems more likely that it was part of the upper seaward current, after it had begun to descend and start landward. Mount Tamalpais, being so near the ocean and relatively high, would not be a great distance from this turning point. This, too, would explain the anomalous, vertical temperature distribution.

RAINFALL ON DAYS WITH AIR TEMPERATURE BELOW THE FREEZING POINT.[1]

By S. TAKAYAMA.

(Abstract.)

When the air temperature near the earth's surface is below the freezing point [0°C.] precipitation generally takes the form of snow. But there are many instances of the falling of ordinary raindrops in the hours during which the mercury stands far below the freezing point. The author has picked out 36 cases in all from the meteorological registers kept at the meteorological observatories at Hakodate, Sapporo, and Nemuro for the 15 years from 1897 to 1912. In the large majority of the cases air temperature was ranging between 0° and −2°C. There were three cases in which the temperature was below −5°C. In one instance it was as low as −7.8°C.

The phenomenon under consideration occurs mostly in the early morning or at night, and is rarely observed in the daytime. Its duration is mostly less than 30 minutes, and the amount reaches scarcely a millimeter. [In Japan] this phenomenon occurs mostly with strong winds or gales from the east.

In the 36 cases referred [to] above, 8 cases were preceded by snow, 2 cases by soft hail [graupel], and 7 cases by sleet [frozen rain drops?]. In two cases it occurred with fogs. In the remaining 14 cases it was raining from beginning to end.

According to the author there are two causes of this abnormal phenomenon. In most cases it may be explained by assuming the existence of the inversion in the

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[1] Sandström, *in* Bull., Mt. Weather Obsy., 1912, 5: 90, fig.

[1] *Reprinted from* Journal, Met'l. soc. Japan, January, 1916, 35:37-8.

vertical distribution of air temperature. In some cases the raindrops are supposed to have been formed in the warm upper current of air and to have fallen to the earth's surface where air temperature is below the freezing point. In the other cases this phenomenon may be explained by assuming that the raindrops have been formed in the ascending current of air highly supersaturated with aqueous vapor. From thermodynamical considerations the author has shown that when the condensation takes place continuously in the highly supersaturated air, both snow crystals and raindrops are formed even though the air temperature is many degrees below the freezing point.—*T. O[kada]*.

NEWTONIAN CONSTANT OF GRAVITATION AS AFFECTED BY TEMPERATURE.[1]

By P. E. SHAW.

[*Reprinted from* Science Abstracts, Sect. A, Aug. 25, 1916, §860.]

This paper deals with the possible existence of a temperature coefficient in the law of gravitation and gives an account of experiments made to discover this coefficient. The apparatus used is of the Cavendish torsion-balance type, and the range of temperatures was from 15° to 250°C. The investigation has extended over a number of years and was carried out in a vault of the physics department of University College, Nottingham. It yields evidence for a positive temperature effect of gravitation and measures its value.

The accumulation of negative results in the experimental study of gravitation is remarkable. In consequence of the indifference of the gravitative force to changes of conditions (other than those given by the simple law $f = GMmd^2$), none of the many theories of gravitation so far propounded has received general acceptance for lack of data wherewith to test them. Some recent theories which consider the possibility of temperature effect are the following: N. Morazov (1908) advanced a wave theory in which the attraction of masses would vary with temperature; G. Mie (1913) gave a theory of matter which includes among its corollaries a temperature coefficient of 10^{-13} per degree C. to the so-called Newtonian constant; N. Bohr (1913), in a paper on the constitution of the atom, assumed that gravitation like radioactivity is unaffected by all physical and chemical agencies.

Previous determinations of the Newtonian constant have been made at ordinary temperatures only, special care being taken to maintain uniformity in temperature throughout the apparatus used; otherwise convection in the air or strains in the movable system might produce grave errors. This is shown repeatedly in the well-known researches by C. V. Boys and J. H. Poynting. The necessity of providing a steady temperature about the delicate parts of the apparatus has previously been considered an insuperable bar to any direct experiment to discover a temperature effect for G. Yet indirect investigations have been made. Poynting and Phillips (1905) counterpoised a mass of 208 gm. on a balance and varied its temperature between 100° and −186°C. They came to the conclusion that the resulting change in weight, if any, was less than 10^{-9} per degree C. for the range 100° to 0°C., and 10^{-10} per degree C. for the range 0° to −186°C.

Another balance experiment on change in weight with temperature by Southerns (1906) led to a somewhat similar result.

In looking for a method to continue and extend these researches it is observed that a weight of say, 1 gm., can be determined on a balance to 10^{-8} under favorable conditions, whereas in a gravitation apparatus, like that of C. V. Boys, the attraction of one mass on another can not be found with greater accuracy than 10^{-5} at the utmost. Thus, apart from other reasons, it would be futile on the latter type of apparatus to look for a temperature effect between 100°C. and −186°C. on the small mass, m, since the above negative results have established the case with the greatest possible accuracy. But, in these balance experiments of Poynting and Phillips, the large mass M (in their case the earth) was unchanged in temperature. Now M is incomparably larger than m and might have a preponderating influence, whereby change of *its temperature alone* would affect the mutual attraction. In the work referred to, Poynting and Phillips suggested (though without any a priori grounds) the feasibility of some such expression as the following:

$$f = G\left[1 + K\frac{Mt + mt'}{M + m}\right]\frac{Mm}{d^2}, \qquad (1)$$

where K is a temperature coefficient and t, t' are increments in temperatures of M and m. When M/m is very great, this reduces to

$$f = G(1 + Kt)(Mm/d^2) \qquad (2)$$

so that, on the above supposition, the mutual attraction would be influenced by change in temperature of the large mass only.

Admitting the possibility involved in (2), weight experiments must be abandoned in the endeavor to detect a temperature effect in gravitation and an apparatus adopted, having both masses (M and m) under control as regards temperature.

It is supposed by some that Kepler's third law establishes the constancy of G. But the present author has tried to show[2] that this is false, and that the common practice of obtaining the masses and densities of heavenly bodies (sun, earth, planets, etc.) by assuming the invariability of G is at fault. It was there held that in such a view Kepler's laws are strained beyond their legitimate use.

A survey of previous researches on gravitation is then given and affords some slight information as to temperature effect; five cases are noticed.

In this connection it may be noticed that there are three classes of work, the results from which should be distinguished: (1) Change in temperature of both M and m (*indirectly* by Boys, Baily, von Sterneck); (2) Change in temperature of M only (*indirectly* by Mendenhall, *directly* in the present research); (3) Change in temperature of m only (*directly* by Poynting & Phillips).

In the present research a number of early experiments were made in a variety of ways. Finally, a form was adopted closely resembling the Cavendish experiments of Boys; that is to say, the small masses, m, m, were hung at different heights inside an exhausted chamber and were attracted by the large masses, M, M, hung at corresponding heights, but outside the chamber. The small masses were of silver, the large ones of lead. The

[1] Phil. trans., Royal soc., London, May 27, 1916, 216: 349-392.

[2] *See* Science Abstracts, 1915, § 1628.